U S ARMY NATICK LABORATORIES

SPECIAL REPORT
S-4

VISIBILITY MEASUREMENT IN FORESTED AREAS

EARTH SCIENCES DIVISION

NOVEMBER 1964

NATICK, MASSACHUSETTS

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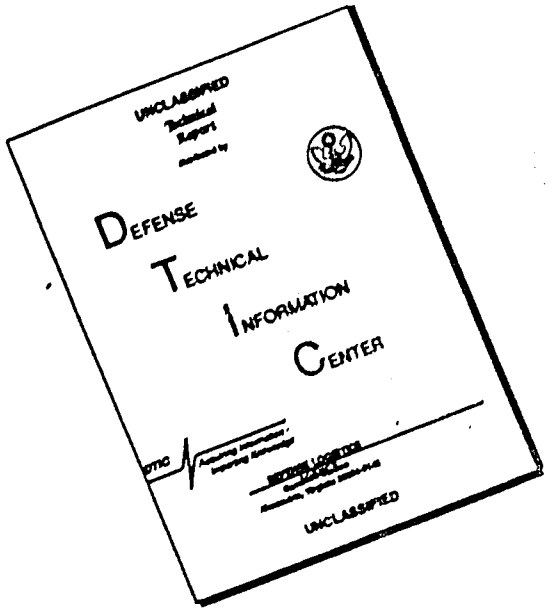

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U.S. ARMY NATICK LABORATORIES
Natick, Massachusetts

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Special Report

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VISIBILITY MEASUREMENT IN FORESTED AREAS

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Geographer

and Division Staff

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FOREWORD

This study brings together the results of field observations of visibility by the Earth Sciences Division, U. S. Army Natick Laboratories, in eight widely-scattered types of vegetation, ranging from tropical forests in Panama to subarctic coniferous forests in the Yukon, Canada, and sets forth a proposed standard system for measuring such visibilities.

Diverse systems of observation were used in obtaining the visibility measurements, some of them partly improvised in connection with other field work. The results are objective and quantitative, and give an indication at least of the approximate ranges of visibility, and of the gross differences and similarities in visibility caused by different types of vegetation. The conclusions represent a distinct contribution to an understanding of visibility problems in a vital field where there was a complete absence of factual knowledge, aside from two prior pilot studies by this Division (References 1 and 3), and a reconnaissance study by the Corps of Engineers (8) based upon the MLABS experience.

The most important contribution of this paper is the proposal of a standard system for measuring visibility in vegetation. The system is based upon the principle of the Secchi disk, an extinction device formerly used in standard oceanographic measurements of transparency in the sea. The system is simple and effective; it can be used by the field observer in connection with other studies, without elaborate special equipment and with minimum advance training. A dull white disk, 30 cm in diameter, of paper or other material, is the basic equipment needed to enable a traveler to bring back quantitative measurements of visibility that can be compared with those made in other regions.

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ABSTRACT

This report summarizes and evaluates results of visibility studies conducted in a tropical deciduous forest, Mediterranean-type forests, mid-latitude mixed forests, and a high-latitude coniferous forest, together with an evaluation of the measurement techniques employed in these studies. Based on this evaluation, it is recommended that a Secchi disk (a flat, dull-white surface), mounted on a tripod of local materials, be used as a standard visibility measuring method for forested areas. By using this standard system, comparable visibility data will be obtained from representative stands of vegetation under various environmental conditions.

VISIBILITY MEASUREMENT IN FORESTED AREAS

1. Introduction

The distance that a soldier can see or be seen is a deciding influence in planning many Army tactical problems. The field commander's decision and plan, direction of movement, employment of weapons, observation, laying out of fields of fire, choice of cover and concealment, and selection of camouflage are only a few tactical activities for which visibility is required. A knowledge of visibility limitations resulting from natural environmental factors is essential in operational planning. Required visibility data include both the maximum, minimum, and usual distances at which an individual using natural cover for concealment can be observed, and the distance at which an individual can be positively identified.*

In order to provide these data, areas of forest, woodland, and bush were selected for study inasmuch as they are the most critical of the natural environmental features which limit visibility (Fig. 1). However, much of the presently compiled information on visibility conditions in forested areas is not strictly comparable because of lack of uniform study methods. Future visibility investigations should be conducted in a uniform manner, with standardized measurement techniques, in order to yield comparable data.

The purpose of this report is (1) to summarize previous visibility studies conducted by NLABS investigators, (2) to compare methods used for obtaining the required data, and (3) to suggest a standard technique for visibility measurement.

2. Summary of Visibility Investigations

The first systematic survey of visibility in various types of vegetation to be initiated by the Quartermaster Corps (predecessor to U.S. Army Natick Laboratories) was a contract study undertaken by the American Geographical Society. Dr. Robert Drummond carried out field work in a number of vegetation types in the United States, and his results were published in 1956 as a Technical Report of the QM Research & Engineering Command (3). In 1962 a preliminary investigation of visibility in a tropical deciduous forest was conducted by Dr. Robert Anstey, geographer with the Natick Laboratories; his results were published in 1963 as a Special Report of the Earth Sciences Division (1). These studies are summarized in the following section.

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* Positive visual identification is defined as ascertaining specific characteristics of a remote object (i.e., size, shape, color, and position), not merely shadow, reflection, flash, outline, or movement.

Three other visibility studies by investigators of the Natick Laboratories are reported here for the first time. In March 1963 experiments with various types of targets were carried out by Mr. John James in oak woodland and chaparral in central California; these studies were continued in August 1963 in a coniferous forest near Nevada City, California. Also in August 1963, visibility in a coniferous forest was measured by Mr. James Havens at Kluane Lake, Yukon Territory, using a human target. In September and October 1963, Misses Norine Mattimore and Sarah Wollaston measured the visibility in a mixed broad-leaved and coniferous forest at Sudbury, Massachusetts, using both human and artificial targets.

a. Tropical Deciduous Forest

This investigation consisted of measuring the horizontal distance over which a camouflaged target can be seen in a representative tropical deciduous forest (10). The study was conducted at two vehicle evaluation test course areas approximately 60 miles east of Panama City, R. P., in September and October 1962 (1). October is the rainiest month of the year, and foliage is at a maximum at this time. The camouflaged target was Mr. Angelo Giarratana, wearing the standard U.S. Army utility uniform, shade OG 107, including tropical DMS boots and the standard field cap. Both the observer, Dr. Robert Anstey, and the target were erect at all times during the observations. Noise was controlled. The observer had uncorrected 20/20 normal color vision.

A total of 360 observations of visibility was made, consisting of 4 observations (1 in each of the cardinal compass directions) at each of 90 sites. Photographs were taken of the target at given paced distances, i.e., 10 feet (3.1 m), 25 feet (7.6 m), 50 feet (15.2 m), 75 feet (22.9 m). This was usually done at a spot just before the target became completely blocked from the observer's view by intervening vegetation (tree trunks, leaves, vines, and underbrush).

The first series of observations was made of the camouflaged target moving away from the observer to the given distances, or until the target moved out of sight. It became apparent that this technique was faulty inasmuch as the observer could see parts of the target moving from point to point, even though the target was obscured from view most of the time. Also, the observer's eyes were focused on the exact location of the target and he could hear the target moving through the vegetation, or see the movement of vegetation being pushed aside. As a result, greater distances were observed and recorded than would have been obtained without these locating events. A second technique was then employed in which the camouflaged target was pre-positioned, erect and motionless, at every second site prior to the arrival of the observer. Positions were selected at random. In this series the observer was unable to see the target at distances as great as those in the same sites when the observer was able to see the target moving. In fact, in many instances the observer came

within 10 feet (3.1 m) of the target before seeing any part of it; on two occasions the identification was made at a distance of only 5 feet (1.5 m). The greatest distance at which positive identification could be made of a pre-positioned target was 60 feet (18.3 m). Only 2 percent of the observations located the target at distances of 50 feet (15.2 m) or more with pre-positioning; the mean distance was approximately 21.5 feet (6.6 m). In the previous series of observations, where the target moved away from the observer, the average distance of the observation series was approximately 48.5 feet (14.8 m). In this series, the range of observations was from 10 feet (3.1 m) to a maximum of 100 feet (30.1 m) (one identification). In over 60 percent of all observations with this technique, the maximum distances over which a camouflaged target could be identified in a tropical deciduous forest were between 35 (10.7 m) and 55 (16.8 m) feet.

b. Mediterranean-Type Forests

This study was made in subtropical dry-summer environment; the name Mediterranean is often used to describe this type of environment because its greatest extent is in the Mediterranean region. Preliminary investigations were made in March and August 1963 by John W. James and an assistant, Wyatt James.

In the Montane coniferous forest of the lower Sierra Nevada, measurements were made at 3 sites (see Appendix A for site descriptions) on the western slope near Nevada City, California, in representative stands consisting of ponderosa pine, sugar pine, Douglas fir, incense cedar, and manzanita brush. Measurements were also made in an area of chaparral in the Sierra foothills near Auburn, California, and in the Santa Lucia Mountains of the Coast Range. At each site 20 observations were made, including one sighting in each cardinal direction and four in each compass quadrant. In one series of observations the disk was the target; in the second the assistant was the target. The assistant wore a parka shell, shade OG-107, and held a 6-inch (0.2 m) glossy white disk 6 feet (1.8 m) above the ground. The observer paced away from the target until it became obscured from sight, and noted the following visibility distances:

	Elevation			Maximum		Mean		Minimum	
	(ft)	(m)		(ft)	(m)	(ft)	(m)	(ft)	(m)
Wolf Mountain (chaparral)	1600	484	Disk	560	170.7	130	39.6	85	25.9
			Man	490	149.3	95	28.9	50	15.2
*Harmony Ridge (open coniferous)	2700	818	Disk	450	137.1	375	114.3	340	103.6
			Man	375	114.3	300	91.4	255	77.7
Five Mile House (open coniferous)	3700	1121	Disk	400	121.9	340	103.6	390	88.4
			Man	320	97.5	250	76.4	205	62.5
Five Mile House (dense coniferous)	3700	1121	Disk	115	35.1	95	28.9	60	18.2
			Man	85	225.9	65	19.8	40	12.1

* See Figure 10 for photograph.

The maximum distances indicated were obtained only in bright sunlight, due to reflection from the glossy disk, or when the assistant was moving. In the chaparral the maximum distance was obtained when the target was taller than the brush. The average height of the vegetation in this particular test area was 6 feet (1.8 m)*; targets taller than this could be seen for almost unlimited distances (restricted only by slope and isolated higher bushes) but shorter targets could only be seen up to 50 feet (15.2 m) away. Long lines of sight (500 feet [152 m]) or more were possible for erect observers in the chaparral, but prone observers could see only 70 feet (21.2 m) to 100 feet (30.4 m) in this test area.

In the Hunter Liggett Military Reservation in the Santa Lucia Mountains of central coastal California, in oak woodland and chaparral brushland, measurements were made respectively in representative stands of valley oak and interior live oak, and in an area of chaparral dominated by chamise, yerba santa, buckbrush, and manzanita species.** Only four measurements were taken in each of these locations (one in each cardinal direction) with the assistant holding a target (a sheet of 8-1/2 by 11 inch white paper on a clipboard) 7 feet (2.1 m) above the ground. The following visibility distances were noted:

	Elevation			Maximum		Mean		Minimum	
	(ft)	(m)		(ft)	(m)	(ft)	(m)	(ft)	(m)
Oak/grassland	1040	315	Rectangle	1175	358	940	287	835	254
			Man	1000	304	820	250	725	221
Chaparral	1580	476	Rectangle	100	30.4	80	24.2	40	12.1
			Man	70	21.2	40	12.1	15	4.5

c. Mid-Latitude Mixed Forests

(1) Eastern Massachusetts

At the U.S. Army Natick Laboratories Annex, Sudbury, Massachusetts, five visibility sites were selected at random within the various types of vegetation represented in the reservation (Fig. 2). The area is in the Transition hardwood-white pine-hemlock Forest Zone (6). In all, 326 measurements were made by Norine Mattimore and Sarah Wollaston, during

* Some stands of chaparral were 12 (3.6 m) to 14 (4.2 m) feet in height. Mature chaparral species are so arranged that the main stem assumes a trunk-like structure with the lower branches approximately 1 to 2 feet above the ground. See Figure 9 for photograph.

** Chaparral species are characteristically evergreen. Valley oak, (Quercus lobata) is deciduous in winter.

three visibility studies in September and October 1963. Both the observer and the target wore shade OG-107 field clothing including standard field cap.

In the first study, three experiments were conducted: observer pacing away from the target, target pacing away from the observer, and observer searching for a pre-positioned target. Both the observer and the target remained erect during the observations, and their paces were equated to feet and inches. In the first two experiments sightings were made from four directions and averaged. It was found that a stationary target could be identified from 38 (11.6 m) to 143 (43.6 m) feet (av. 77 feet [23.5 m]) and a moving target could be identified from 51 (15.6 m) to 216 (65.5 m) feet (av. 115 feet [35.1 m]). The pre-positioned target was located at distances from 48 (14.6 m) to 84 feet (25.6 m) (av. 70 feet [21.3 m]). In the latter experiment the distances obtained were greater than those that would be expected under normal circumstances because (1) the observers knew the approximate location of the target and (2) they were well acquainted with the area, having obtained experience from several series of observations.

The second study included experiments comparing (1) the visibility of a human target wearing OG-107 field clothing versus the same target wearing a white shirt, (2) a clipboard target covered with OG-107 cloth versus one covered with white cloth, and (3) each of the above, sighted from both the erect and the prone position (Fig. 5). When the human target was sighted alone, the target faced away from the observer. When using the clipboard, the human target held the base of the clipboard, five feet (1.5 m) above the ground. In this position the uncamouflaged face of the individual was not visible. It was noted that the human target wearing a white shirt, when viewed from the erect position, could be seen much farther than any other target (av. 131.5 feet [40.1 m]). The second greatest visibility was obtained from the same target viewed from the prone position (av. 116.3 feet [35.5 m]). An average of 96 feet (29.2 m) was obtained for the white-covered clipboard viewed from the erect position, but the distance in this experiment was not significantly greater than that for the human target wearing OG-107 clothing (av. 88.5 feet [27.1 m]). It was noted that ferns, tall grass, terrain irregularities, and stone walls limited the distance that a prone observer could identify either the green or white target. In an area with low branches but little undergrowth, the legs of the human target could be seen from the prone position, but no part of the target was visible from the erect position. In every experiment, however, the average of all sightings showed that targets could be identified at greater distances from the erect position.

These findings were rechecked in a third study, which also included comparison of erect and prone observations of the visibility of a Secchi-type disk (7) in the same sites (Fig. 8). The disk used was a dull white card, 1 foot (0.3 m), in diameter, mounted on a tripod constructed with

local materials. The base of the disk was 5 feet (1.5 m) above the ground and it was turned to face the observer prior to each observation. During the observations no one remained near the disk to aid in its location.

On 8 October 140 observations were made; the four final observations were made on 21 October 1963. Due to increased leaf fall, the visibilities measured on the latter date were approximately 150 feet greater than those made on 18 September 1963 in the same area. However, only minor differences were noted between the observations taken on 8 October 1963 and those taken on 18 September. In five instances (in 16 observations) the difference in visibility distance measured on the two dates in the same areas was only 2 (0.6 m) to 7 (2.1 m) feet, and in eight instances the difference was only 10 (3.1 m) to 20 (6.1 m) feet (see Appendix B for individual study data). These experiments demonstrated that a small white target is easily obscured by branches, and is more difficult to see than a human target.

(2) Central United States

The visibilities in a total of 392 forest stands throughout the United States were measured by Robert R. Drummond in 1952 (3). Measurements were taken in 147 deciduous stands, 126 evergreen stands, and 111 mixed deciduous and evergreen stands; the remaining 8 were of other types. The vegetation at each site was classified by the Kuchler system (4). In these studies the observer walked away from a "visibility object" and noted the distance at which the object became blocked from view by the vegetation. The visibility object used as a standard throughout the project was a green cylinder 6 feet (1.8 m) in height and 1.5 feet (0.4 m) in diameter. The cylinder was constructed from a framework of metal pipe and plywood and was fitted with a cover of canvas cloth dyed a medium-dark green (shade OD 8). The size of this target was chosen to correspond to the dimensions of a man plus his military equipment. The size also bears some significance in military mathematics; a six-foot object subtends an angle of 1 mil at 1000 yards. Various sizes of stakes and signs were tried but none proved as effective as the cylinder in duplicating data obtained when the human form was used. The standard visibility object could be readily interchanged with a human being dressed in Army fatigue green, without noticeable bias in resultant data.

Observations were made only on clear days when the sun was high; an attempt was made to keep the target continuously in view, avoiding large trees. It was found that visibility in deciduous and coniferous forests of the United States exceeded 100 yards (91.4 m) on 19 out of 392 observations. Twenty-five percent of all stands studied by Drummond had visibilities between 40 (36.5 m) and 50 (45.7 m) yards. Nearly half had visibilities between 30 (27.4 m) and 60 (54.9 m) yards.

Drummond found that on the whole there was no marked difference between visibility in deciduous and coniferous stands in summer. Where

vegetation was mixed coniferous and deciduous, the conifers tended to be the dominant factor in limiting visibility. In deciduous growths, visibility was about 40 percent greater in winter than in summer. Visibility was greater in interrupted stands of deciduous vegetation than in stands where the branches of one tree touched the branches of the next tree. In deciduous forests, visibility was greatest in stands of medium height. Tall deciduous trees usually were accompanied by relatively dense undergrowth, often including vines, which reduced visibility. Likewise, where trees were low, undergrowth was a large factor in impeding visibility. Low trees were also more likely to have low branches that interfered with visibility.

In coniferous vegetation, visibility did not vary appreciably from season to season. In tall coniferous vegetation, visibility was greater in interrupted stands. In coniferous vegetation of medium and low height, visibility was greater in continuous stands than in interrupted stands. The density of the overhead canopy of branches and foliage restricted the amount of light that reached the target and produced dappled effects which made identification uncertain in some instances. Among conifers and in mixed coniferous and deciduous forests, visibility tended to increase with the height of the primary vegetation covers (as opposed to undergrowth).

Visibility tended to decrease as the height of the undergrowth increased. Visibility was greatest when the height of the undergrowth was less than 3 feet (0.9 m); it was least when the height of the undergrowth was more than 6 feet (1.8 m). Vines in undergrowth greatly reduced visibility. On an average, the reduction was about 36 percent.

d. High-Latitude Coniferous Forest

During August 1963, 120 visibility measurements were made by James Havens in a mature spruce forest near Mile 1055 (Kluane Lake) on the Alaska Highway, Yukon Territory, Canada (Fig. 3). This forest appeared to be the oldest in the area (trees probably more than 100 years old), and was the least dissected by stream beds. In this forest, 10 sites were located on a rectangular traverse measuring approximately 800 yards (731.5 m) by 300 yards (274.3 m), and an additional 5 sites were selected at random within the rectangle. An average of 30 spruce diameters at a typical site was 6 inches (0.2 m) at a height of 5 feet (1.5 m) above the ground. The area contained undergrowth and dead-falls.

At each of the cardinal directions an assistant (Sgt. D. E. Saarela, USMC) in USMC utility dress (shade M225) paced away from the center point of the site, giving 4 measurements. The directions were then rotated 45° and the target donned a bright red sweater; 4 more measurements were taken, giving a total of 8 measurements for each site (Fig. 11). Although one would expect to see a red sweater at a greater distance than the green utility dress, the frequency table indicates the opposite (see Appendix B).

This difference in the means for ungrouped data, 141.7 ft (43.2 m) (green) and 135.1 ft (41.2 m) (red), is not statistically significant and therefore the two samples have been combined (Fig. 6). The over-all average visibility of 138.4 feet (42.2 m), which can be considered representative of the area selected, is approximately three times greater than the moving target mean for a tropical forest (Fig. 4) but only one-fifth greater than the mean found for a mid-latitude mixed forest (Fig. 4).

3. Comparison of Techniques

a. Camouflaged Target Standing

The problem in the present series of visibility studies is to determine the distance that a soldier can see or be seen in various forested areas. Military activities involved would include attack, patrolling, picket and guard-post walking, and tactical maneuvers in which the soldier would be standing erect at least part of the time. A standing man is a large target; for the purposes of visibility studies, this position is convenient and permits rapid observations. Also, the front facing surface area of a standing man compares favorably with the standard silhouette target used in Army marksmanship training, except that the height of the target above the ground is not controlled. The different sizes of men used in different studies is a factor which must be considered in comparing the results of visibility measurements. Figure 4 gives the distances at which a standing human target, or a near representation, could be seen in various types of forested areas.

These data are not considered to be definitive measurements of visibility. It is assumed that additional studies made with the various human targets would yield an average visibility distance with a high degree of reliability. It is not practicable to designate the dimensions of a standard human target for visibility measurements. Because of the varying sizes of human targets, a standard visibility object with the approximate dimensions of a standing man should be used as a target.

b. Target Moving - Observer Moving

In order to determine which method of observation would yield the most realistic visibility data, several techniques were utilized. In two of the studies described in this report, the observer walked away from the target to a point where the target could no longer be seen; in two studies the target paced away from the observer to a point where he could no longer be seen; in two studies both techniques were used. In the Tropical Forest Study, it was found that the target could be seen at a much greater distance when it moved away from the observer than when the observer attempted to find it in an unknown, pre-positioned location. The average distance for the former was 48.5 feet (14.8 m); for the latter, 21.5 feet (6.6 m). In the Mid-Latitude Mixed Forest Study (Sudbury, Massachusetts) the

observer walking away from the target obtained an average visibility distance of 77 feet (23.5 m), whereas when the target walked away from the observer, the average distance was 115 feet (35.1 m). The average distance that a pre-positioned target was observed was 70 feet (21.3 m) in this study. Noise, movement, and continuous observation of the target were locating factors when the target walked away from the observer. In the instances where the observer walked away from the target, he frequently found, when turning to look back, that the target was lost to view and he had to pace back to locate it. This was due in part to (1) a loss of the exact angle of observation, (2) an inability to recognize a partly obscured target, because his eyes were focused on intervening branches of trees, and (3) the changing shape of the target, which was not immediately recognizable. In the Mid-Latitude Mixed Forest Study, when the observer walked beyond the point where the target became obscured, and then paced back to note where the target was again visible, the visibility distances were from 10 to 20 yards (9.14 to 18.2 m) less than those obtained when the observer walked away from the target, keeping it continually in sight. In conducting a pre-positioned target experiment, the necessity for experience precludes its use in each new forest type for an untrained observer. For example, the observers came within 5 feet (1.5 m) of the target in both a tropical forest and a mid-latitude forest before this target was observed. With practice the target could be located at much greater distances. Also, the time involved in searching is nearly three times that for standard target observation. In order to obtain a realistic visibility distance, the observer should walk to a point beyond which the target can be seen, turn around, walk back toward the target until it is again seen, and pace the distance from that point back to the target.

c. Observer Standing - Observer Prone

Prone is the normal observing position for forward artillery observers or infantrymen on patrol. It was found that slightly greater distances could be obtained from observers standing erect than from those in the prone position. Observers standing erect were not hindered by low brush, boulders, or minor terrain differences. In the Mid-Latitude Mixed Forest Study, for example, the erect observers were able to locate their targets at an average distance of 96 feet (29.2 m), whereas the prone observers obtained an average of 90 feet (27.4 m). Due to the interference of low vegetation (ferns, grass, shrubs, etc.), more realistic visibility measurements can be made from the erect position in most forested areas.

In areas of undulating terrain, there is no advantage for an observer standing erect over a prone observer when (1) observing from the top of a hill, or (2) when looking uphill from the floor of a narrow valley. Also, when viewing over distances greater than 100 yards (91.4 m), the advantage of an observer standing erect is negligible.

d. White Target - Green Target

White camouflage items utilized on targets are frequently not visible for distances greater than 50 yards (45.7 m) over snow or ice surfaces. However, studies of visibility in snow were not conducted as a part of the program covered in this report. White targets may also be confused with quartz, limestone or similar light-colored rock exposures, or stands of white birch trees in a forest where various shades of green are dominant. In general, green targets are less visible in a forest than white targets. For example, in a study conducted by the U. S. Army Infantry Board at Ft. Benning (9), all of the observers were able to identify men wearing white tee shirts at 1400 meters (4593.2 ft), but only one observer in 10 was able to identify a man wearing the OG 107 field uniform at 190 meters (623.4 ft). In these studies, the target was located in an area of trees and shrubs, but the observers were stationed at varying distances across an adjacent open field. Shorter lines of sight would have resulted if the entire area had been wooded. In a mid-latitude mixed forest an average of all visibility distances of 124 feet (37.8 m) was obtained by Mattimore and Wollaston for a human target wearing a white shirt, as against 86 feet (26.2 m) for the same target wearing an OG 107 jacket. When a covered clipboard was used as the target, the average visibility distance was 92 feet (28.0 m) when covered with white, and 71 feet (21.6 m) when covered with shade OG 107 cloth. It will be noted that in these studies the white covered clipboard was not appreciably more visible than the human target wearing green clothing. This was rechecked in the same area two weeks later and it was found that the human target in green field clothing was visible at 96 feet (29.2 m), and the white covered clipboard was visible at 109 feet (33.2 m). These data cannot be compared statistically because of the difference in size of the targets and possible difference in amount and color of foliage.

Some observers have difficulty in distinguishing colors. These observations confirm the findings of the Massachusetts Hunter-Safety Test. Richards (5) points out that a "red cloth is not nearly as conspicuous as a red light and with poor lighting in the woods, red turns dark and is not seen." Individuals with deficient color vision may not see some reds or may confuse reds with greens. When the enlisted men participating in the Hunter-Safety Test were asked to identify colored targets, red was called green, orange, pink, brown, black, dark or doubtful, and white, depending upon the surroundings and lighting.

The camouflage colors used on targets in the studies being evaluated were standard military uniform shades. No attempt was made to compare the visibility distances obtained with various shades of field clothing in forested areas. A pioneer study in this field was conducted in 1963 at Ft. Benning, Georgia (9).

e. Comparison of White Targets

In order to determine the type of target best suited for maximum visibility measurements in forested areas, several experiments were conducted as a part of the Mid-Latitude Mixed Forest Study. These included comparison of a human target wearing a white shirt with the same target wearing a shade OG 107 jacket, and with a clipboard covered with the same shades of cloth, and comparison of a white covered clipboard with a white Secchi disk.

The greatest distance at which the Secchi disk was observed was 529 feet (161.2 m); the greatest distance for the white covered clipboard was 418.5 feet (127.5 m), due to the open nature of the mid-latitude mixed forest in two different localities at the U. S. Army Natick Laboratories Annex, Sudbury, Mass. However, the average distance for the Secchi disk was 130.4 feet (39.7 m); for the white clipboard the average was 146.8 feet (44.7 m). These observations were not conclusive. In three experiments the disk was observed at a greater distance than the white covered clipboard; in two experiments the clipboard was observed at a greater distance. In a pre-positioning experiment, conducted on 8 October 1963, the target was located by the observer through the uncovered clipboard held in the target's hand. The target, wearing OG 107 field clothing was standing erect in a small pine grove, and was identified only because of the "unnatural appearance" of the clipboard.

One advantage in using a white target is the reflection of sunlight from the bark of birch, aspens, poplar, and light colored shrubs, and the leaves of such trees as the silver maple, which "blinded" the observer to background objects. Reflection of a white target in the sun seemed to increase visibility distances when the observer was viewing from a southerly direction without other white object interference. Similarly, when a human target was facing the observer, the face of the observer was usually seen, due to reflection, before any other part of the target, except when the target was wearing a white shirt.

In the Mediterranean Forest Study a six-inch (0.1 m) white glossy disk was used as the target. The maximum distance at which this target was observed was 560 feet (170.7 m) (in an area of chaparral). This distance is only slightly greater than that for the shaded dull-surfaced Secchi disk in a mid-latitude mixed forest. The relative brightness (reflectivity) of a glossy disk is a function of the amount of sunlight impinging on its surface. The angle at which it is held as well as the variation in sunlight may influence visibility. A great amount of the reflectivity of a cloth-covered target or a card disk is lost when the material becomes wet.

f. Comparison of Compass Directions

In the Tropical Forest Study standard compass directions were used merely for uniformity of observations from site to site and comparability in sampling rather than as an attempt to detect possible increased visibility in any direction. It was recognized that longer sight lines would not be obtained from southerly quadrants due to the reduced light conditions in the forest. In the Mid-Latitude Mixed Forest Study a summary was made of sight lines by compass direction. In this study the open nature of the forest necessitated the positioning of the target in a shaded area so that there would not be longer sight lines from the south. Also, studies were conducted during the middle of the day so that low sun angles from the east or west would not result in longer sight lines in those directions. Bright sun on the target, particularly one with a reflecting or glossy surface, is an advantage to the observer. In eight summaries on 18 September 1963 longer sight lines were noted for observations from the north rather than from the south. In six summaries on 8 October 1963 three showed greater visibility from the north than from the south. On 18 September 1963 the longest average sight line, 151.37 feet (46.1 m), was from the west and the next longest was from the east. On 8 October 1963 the longest sight line was from the south due to the existence of an open field adjacent to the wooded area in which the target was located. The observer could see the target from across the field, whereas if the field had been wooded, a much shorter visibility distance would have resulted from this direction. These results indicate that the density of vegetation is a more important factor in locating targets than the advantage of a particular compass direction. Nevertheless, at least four observations from different directions are required for adequate sampling of each visibility site. The most convenient way to achieve this sighting is to use the four cardinal compass directions.

4. Conclusions and Recommendations

The investigations of visibility discussed in this report point to the need for studies in other major types of vegetation, particularly physiognomic types such as the southern coniferous forests in North and South Carolina and the mesquite woodland of Texas. It is therefore recommended that additional studies be conducted to determine the seasonal variation of visibility in all of the vegetative types discussed here (i.e., tropical deciduous forests during the dry season, Mediterranean and mid-latitude mixed forests during the winter season).

To obtain uniform measurements of maximum visibility in forested areas, a standard visibility measurement technique should be established for use in all future studies. It is recommended that the following method be adopted:

a. A representative forest stand should be chosen for the study. A target composed of a flat, dull white, 30-centimeter disk (constructed of

painted cardboard or metal), mounted vertically on a tripod of natural materials*, should be erected in a shaded spot, with the white surface of the disk facing the observer. The observer should remain erect when measuring visibility, but should be free to move from side to side (no more than five degrees azimuth) to keep the target in view. The observer should walk away from the target to a point where the target is no longer visible, walk back to a position where he can again see the target, and then measure the distance from that point to the target. The most accurate and practicable means available (tape measure, optical range finder, or pacing) should be used to make the measurement and the distance should be recorded in feet or meters. The same procedure should be followed for each of four arbitrary compass directions. Considering the extreme irregularity of vegetation even within a single stand of a given "type" and between two successive moments of time, micrometer-like measurements would seem to be unnecessary and wasteful.

b. The testing area should be as level as possible and measurements should be taken on a sunny day. The date, hour and cloudiness should be noted for each series. Observations taken during bright sunshine should be checked against those taken during cloudy conditons. Observations taken at high sun should be checked against those at low sun. While most observations will be on nearly level ground, these should be checked against observations taken in similar environments where the observer is looking up-hill or down-hill.

c. Immediately following the primary measurements, it is desirable that visibility measurements be made in a nearby site having the same vegetation according to a standardized system. In view of the scarcity of uniform stands of vegetation in nature, a large number of observations at different sites within a vegetation type is considered more representative than a similar number from a single site.

d. The sites used should be located on a map and marked on the ground (e.g., with a cairn) so that subsequent measurements can be made at the same spots during other seasons of the year. It is desirable that 35 mm color photographs be made of the sites at the time of the observation.

To insure that valid comparisons of results can be made, it is important to continue experiments with other kinds of targets in the same areas. One other technique involves the use of two additional white disks, one touching the ground and one halfway between the other two on the tripod described above. This arrangement would approximate the height of the

* The support will consist of three poles, seven feet long, with bark in place, tied together one foot from the top. The top of the disk will be fastened to the top of one pole. The legs of the tripod will be spread so that the base of the disk is 5 feet above the ground.

average man, and give line-of-sight targets for prone and kneeling observers in heavy brush.

Military personnel who have trained in forested areas similar to those selected for the study sites, and who have been medically screened for visual color deficiency as well as near and far-sightedness, should be used to locate standard pre-positioned OG-107 colored targets or similar camouflaged targets in major forest types in order to compare the "military visibility" with the "standard visibility" in these area.

5. Acknowledgments

Miss Pernel Leuvelink drafted the maps and graphs used in this report under the supervision of Mr. Aubrey Greenwald Jr., Head - Cartographic Laboratory. Sincere appreciation is extended to Gordon K. Nishimoto for assistance in field work.

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LIST OF ILLUSTRATIONS

Figure No.

Maps and Graphs

Photographs

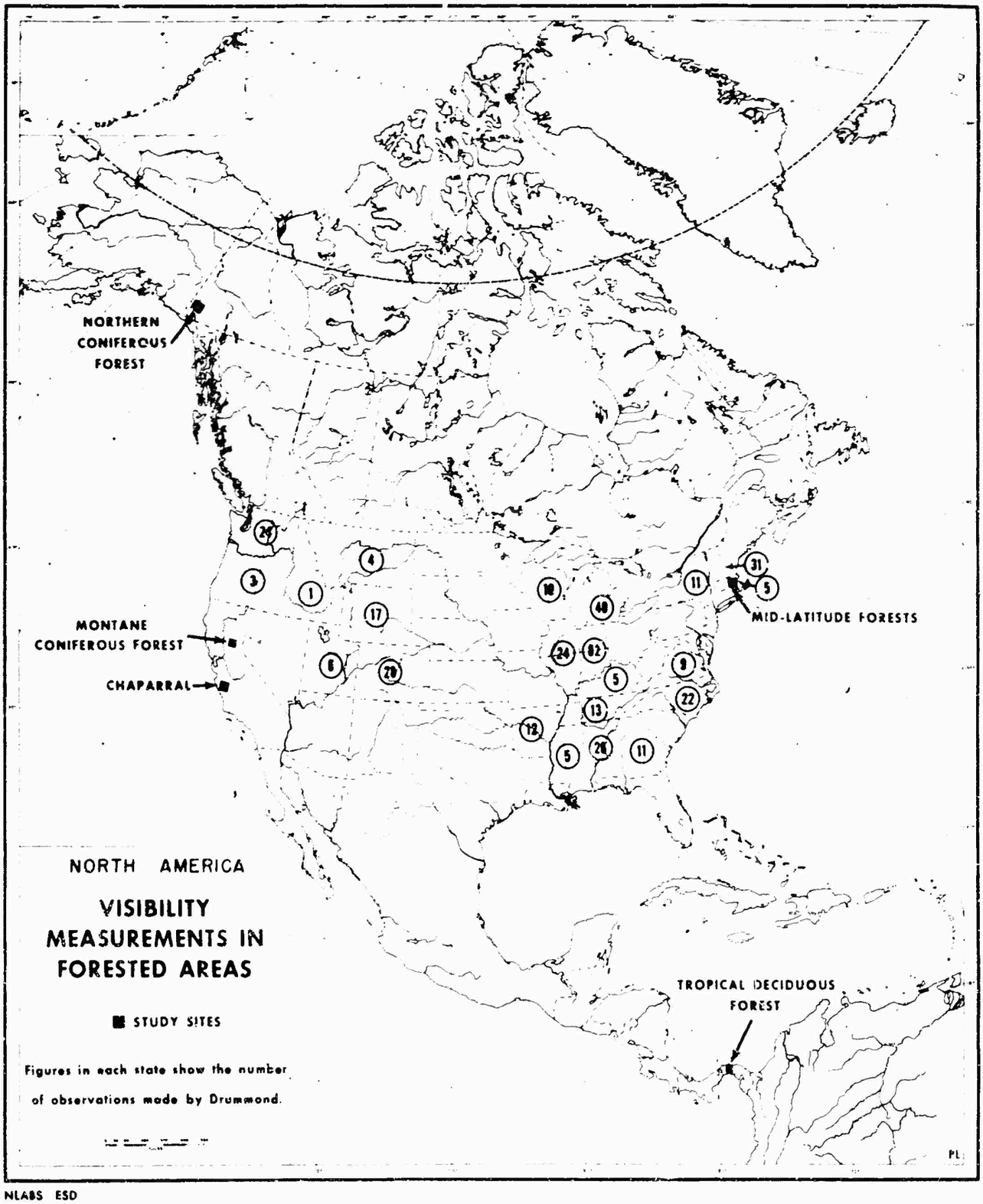
NORTHERN CONIFEROUS FOREST
MONTANE CONIFEROUS FOREST
CHAPARRAL
MID-LATITUDE FORESTS
TROPICAL DECIDUOUS FOREST
NORTH AMERICA
VISIBILITY MEASUREMENTS IN FORESTED AREAS
STUDY SITES
Figures in each state show the number of observations made by Drummond.
NLABS ESD

Figure 1

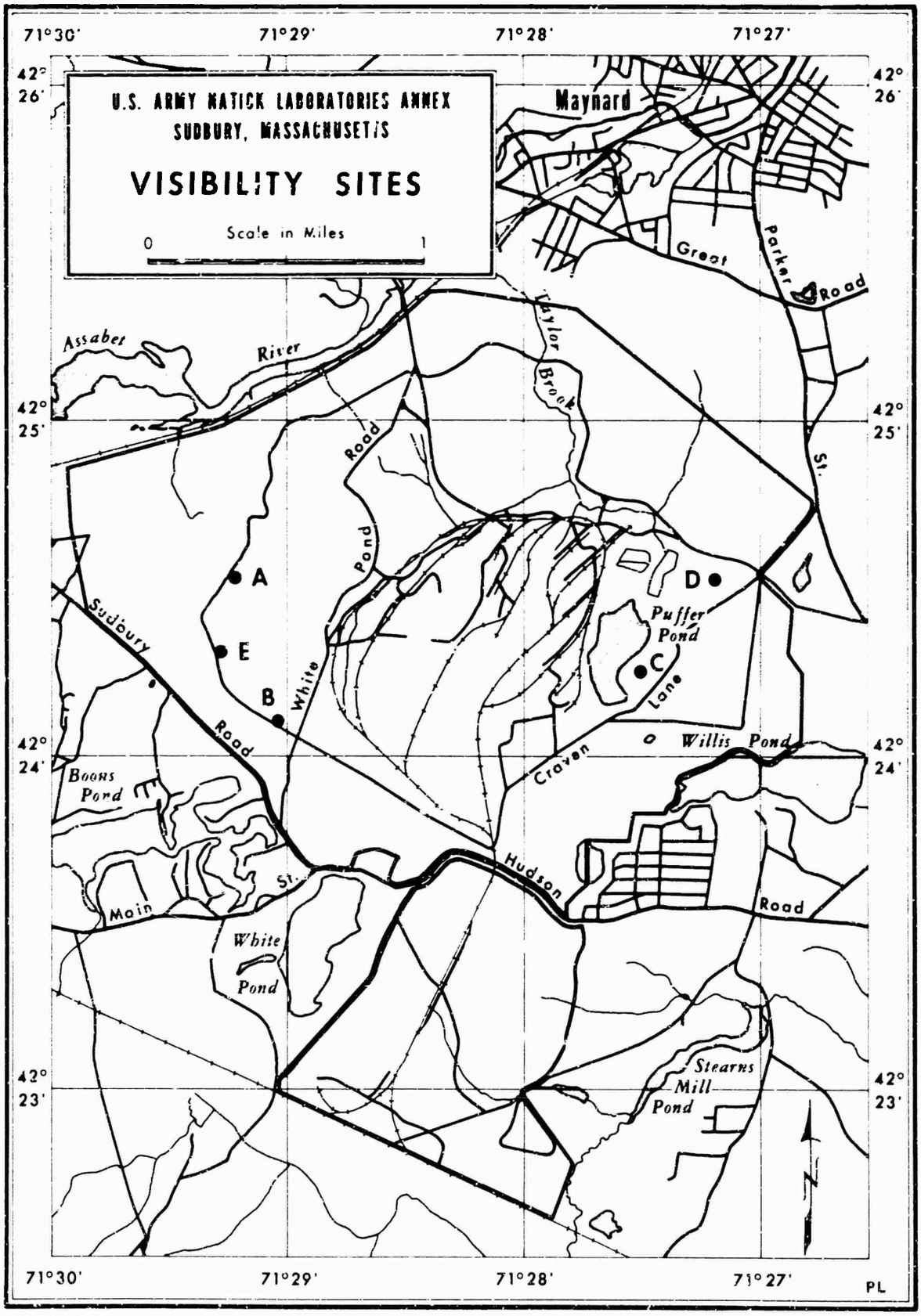

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Figure 2

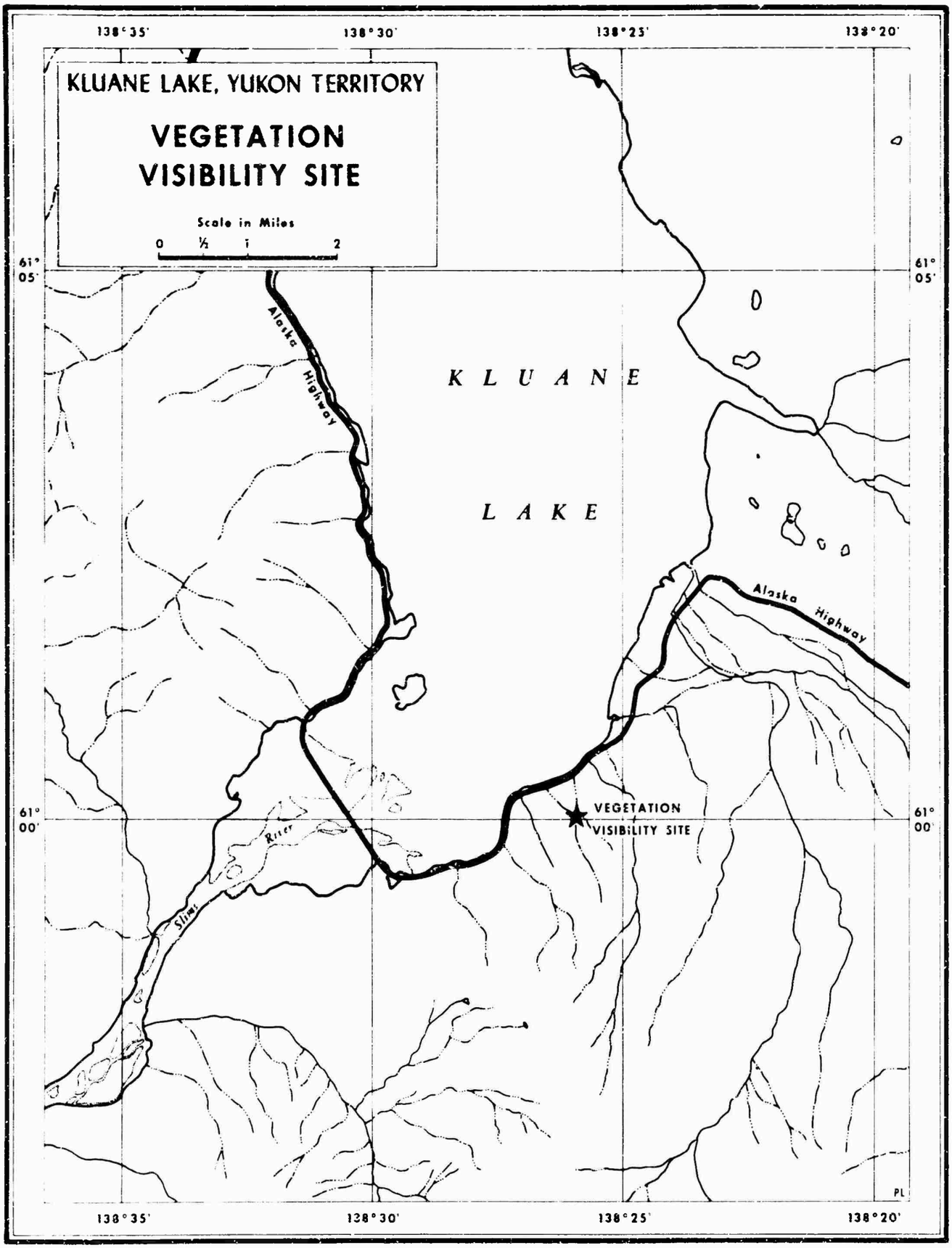

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Figure 3

VISIBILITY DISTANCE IN VARIOUS FOREST TYPES IN NORTH AMERICA

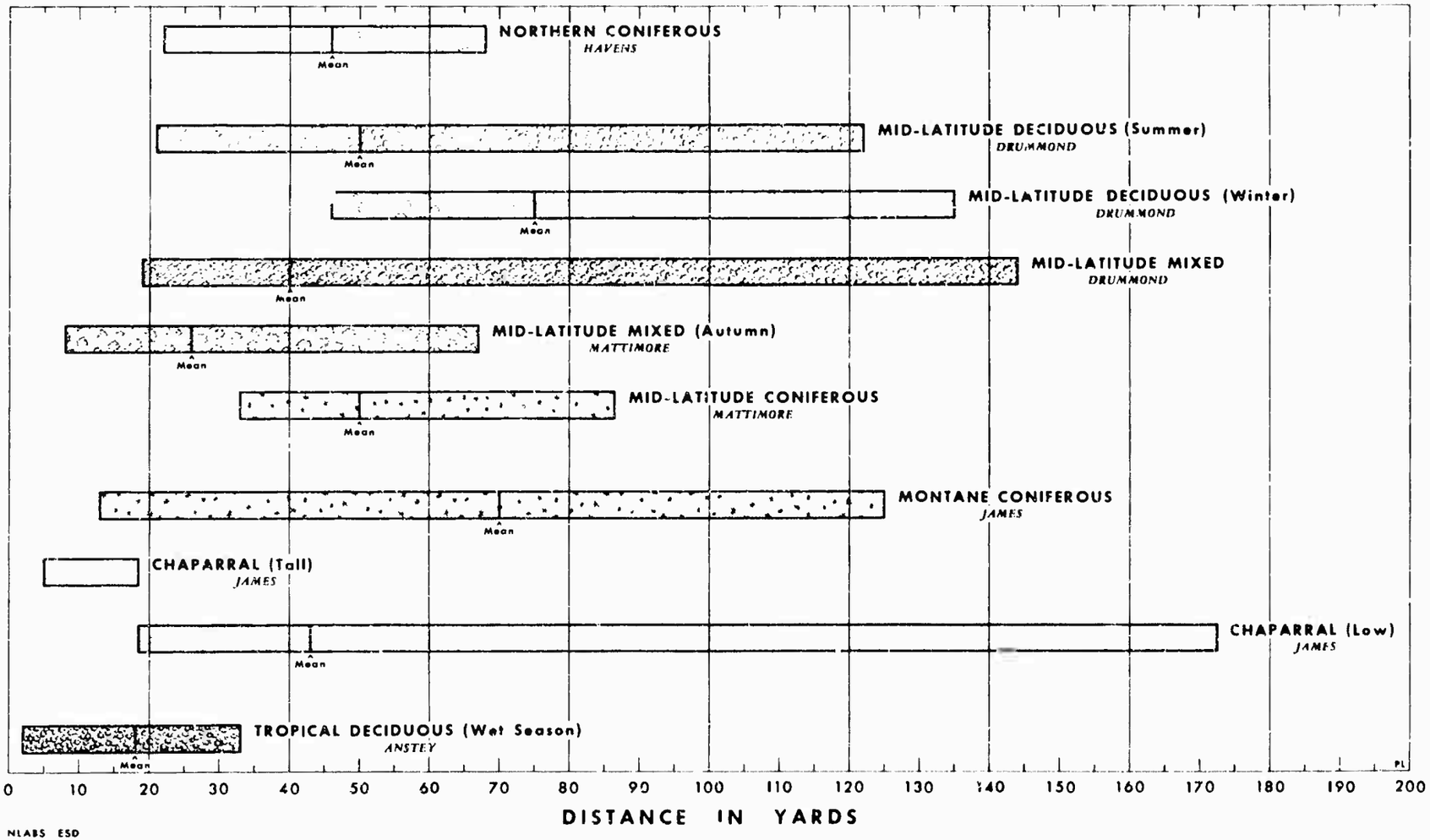

Figure 4

CUMULATIVE FREQUENCY OF MAXIMUM HORIZONTAL VISIBILITY AT A 5-FOOT HEIGHT IN A MID-LATITUDE MIXED FOREST

BASED ON 155 OBSERVATIONS IN REPRFSENTATIVE VEGETATION TYPES AT THE U. S. ARMY NATICK LABORATORIES ANNEX IN SUDBURY, MASS.

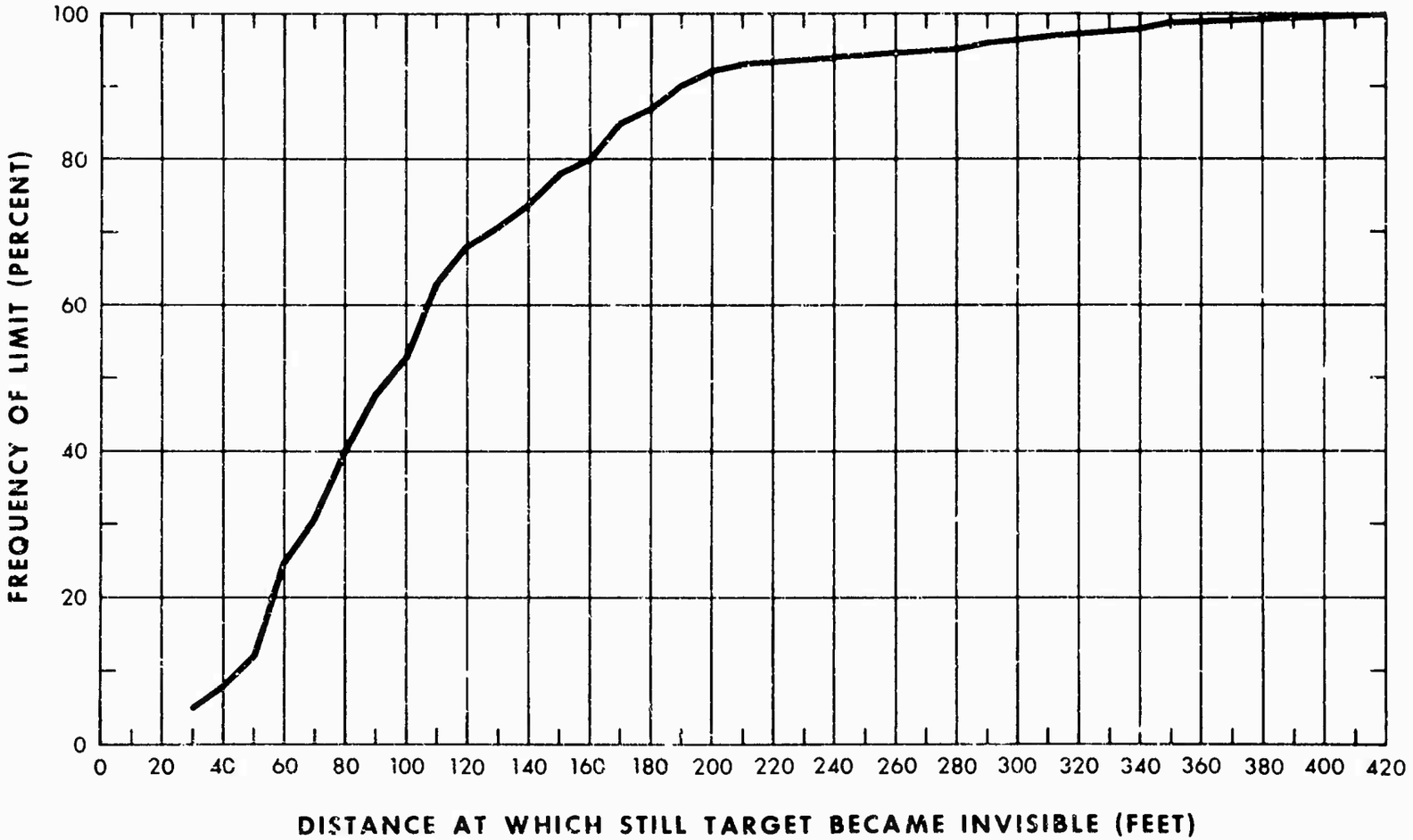

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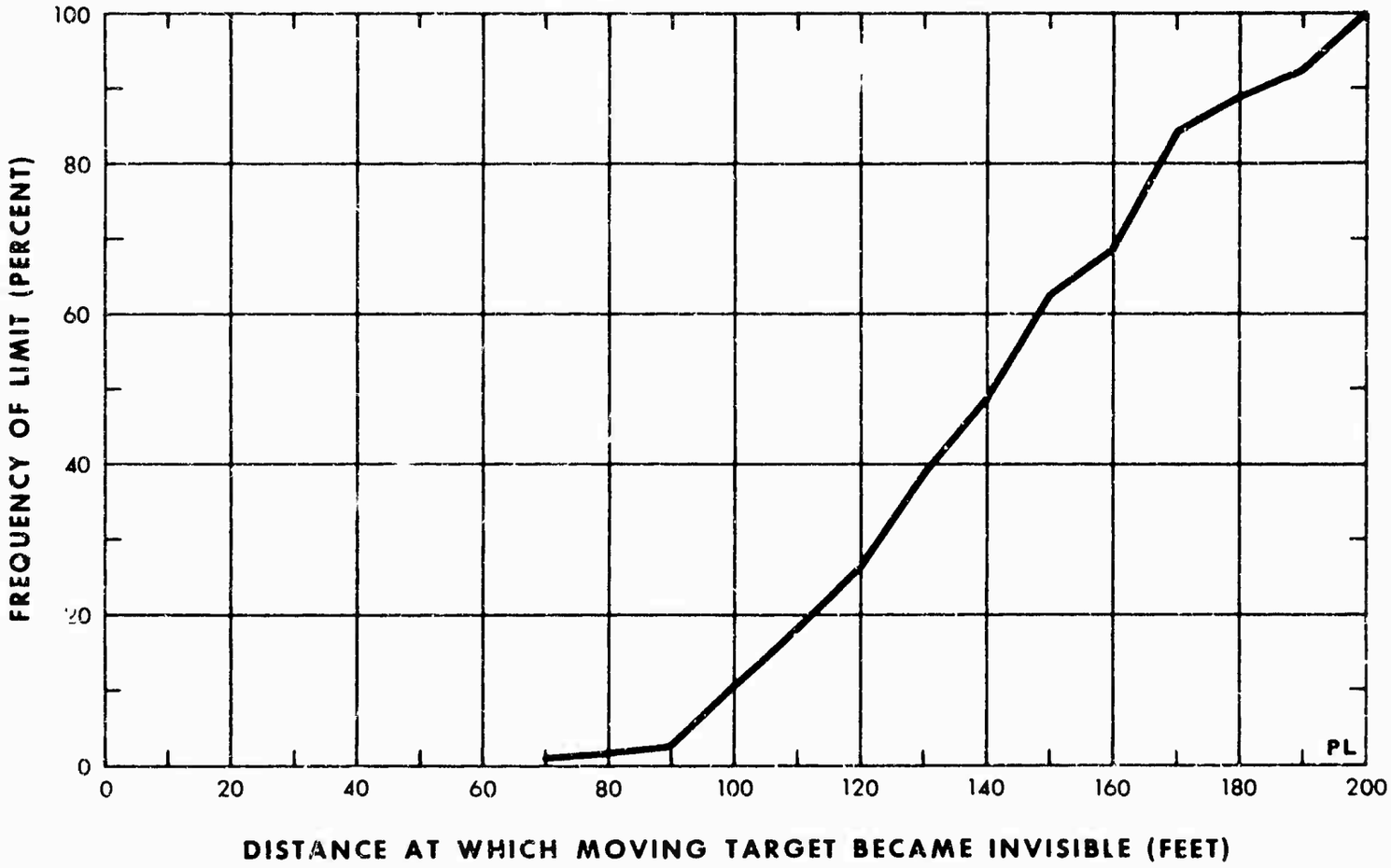
Figure - 5

CUMULATIVE FREQUENCY OF MAXIMUM HORIZONTAL VISIBILITY AT A 5-FOOT HEIGHT IN A NORTHERN CONIFEROUS FOREST

BASED ON 120 OBSERVATIONS FROM 15 SITES WITHIN A 300×800 YARD SPRUCE STAND NEAR KLUANE LAKE, YUKON



NLABS ESD

Figure 6

A COMPARISON OF CUMULATIVE FREQUENCIES OF MAXIMUM HORIZONTAL VISIBILITY, AT A 5-FOOT HEIGHT, OF A MOVING TARGET IN A NORTHERN CONIFEROUS FOREST AND STILL AND MOVING TARGETS IN A MID-LATITUDE MIXED FOREST

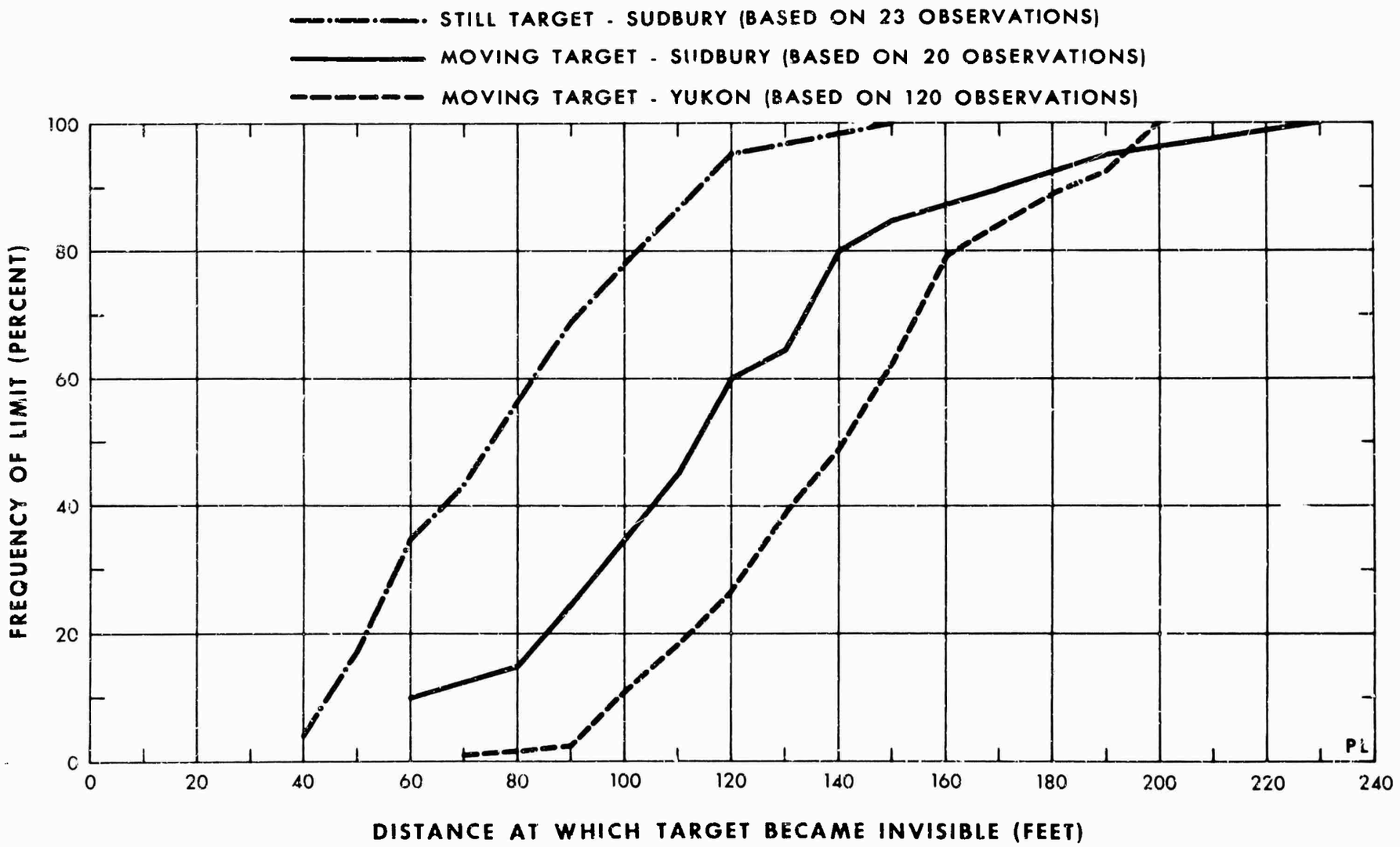


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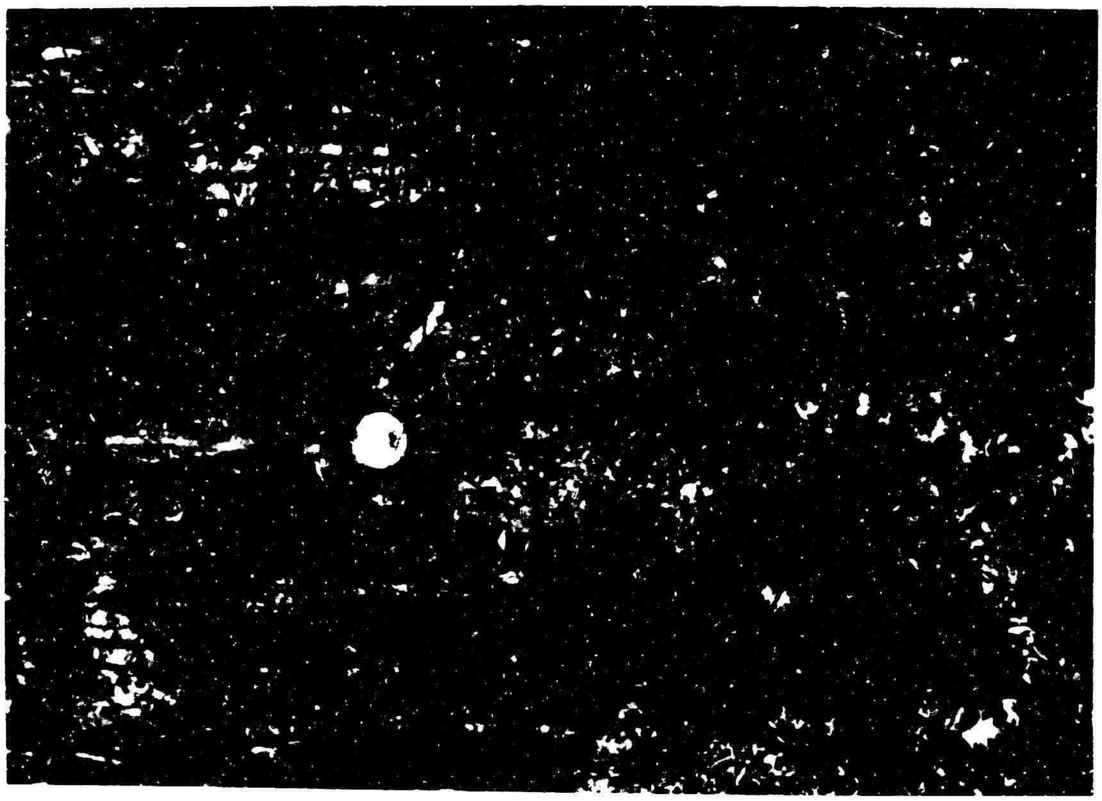
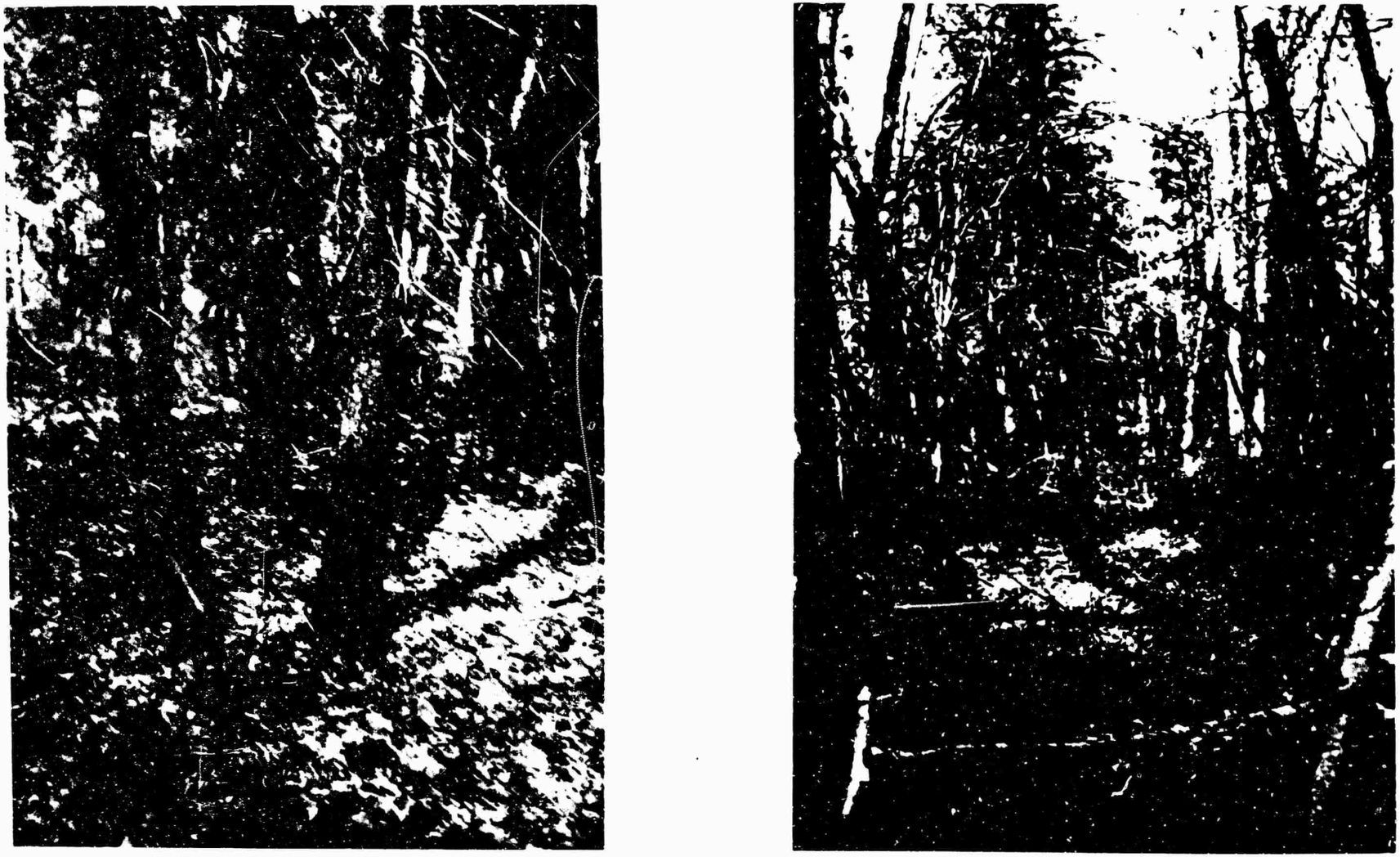
Figure 7



(b)

(a)



(c) (d)

Figure 8. Target disk mounted on a 6-foot tripod at various distances in a mixed forest at Sudbury, Massachusetts, 1400 hours, 21 October 1963, during bright sun: (a) 10 feet, (b) 50 feet, (c) 100 feet, (d) 150 feet.

Figure 9. Stationary human target holding a 6-inch (diameter) plate at 6-foot height in dense chaparall at a distance of 500 feet from the observer at Wolf Mtn. in the Sierra Nevada foothills near Nevada City, California, at 1400 PST, 22 August 1963, during clear weather.

Figure 10. Stationary human target in open Ponderosa Pine forest at a distance of 300 feet from the observer at Harmony Ridge in the Sierra Nevada Mtns. near Nevada City, California, at 1000 PST, 22 August 1963, during clear weather.

Figure 11. Moving human target wearing red sweater at a distance of 30 feet from the observer in the spruce forest site, Kluane Lake, Yukon, Canada, at 1500 YST, 25 August 1963, during overcast weather.

APPENDIX A

Description of Sites Used in the Mediterranean Environment Study

The sites used in this visibility study were located in the Yellow Pine Belt and Foothill Chaparral Belt of the Northern Sierra Nevada near Nevada City, California, in an area of modified Mediterranean climate with fairly high precipitation totals. Average annual precipitation is approximately 55 to 60 inches at the Yellow Pine Belt sites, and 35 to 40 inches at the Foothill Chaparral Belt sites. About 80 percent of the precipitation occurs between November and March, with moderate snowfall in the Yellow Pine Belt.

Harmony Ridge site (2700 feet) - The vegetation at this site consisted of second growth ponderosa or western yellow pine (Pinus ponderosa) forest with a few scattered sugar pine (Pinus lambertiana) and incense cedars (Libocedrus decurrens). The understory consisted of seedlings of the above-mentioned trees, especially P. ponderosa averaging 10 to 15 feet in height and scattered manzanita (Arctostaphylos manzanita and A. patula) averaging 6 to 8 feet in height. A few broad-leaf maples (Acer macrophyllum) of small size (d.b.h. 6 to 10 inches, height 15 to 25 feet) were present along an intermittent stream. Trees of P. ponderosa, P. lambertiana, and L. decurrens averaged 60 to 100 feet in height with d.b.h. varying from 1-1/2 to 3-1/2 feet. Only a very few mature trees (incense cedars in this case) were present with d.b.h. of 3 to 4 feet and heights of 100 to 200 feet. Low ground cover consisted of a very sparse growth of wild wheat, not over 10 inches high and not present at all under a full canopy of evergreen trees. Many dead fallen trees were also present. Trees other than seedlings averaged approximately 40 per acre.

Five Mile House, Site A (open) (3700 feet) - The vegetation at this site consisted of second growth sugar pine (Pinus lambertiana), Douglas fir (Pseudotsuga menziesii), ponderosa pine (Pinus ponderosa), and incense cedar (Libocedrus decurrens) forest with sugar pine the dominant tree. Forest floor cover here consisted of only a few low (2 to 4 feet) broad-leaf maple bushes and a sparse growth of wild wheat in open areas. Trees were of moderate size, being about 80 to 90 years old and averaging 80 to 110 feet in height with trunk diameters mostly in the 1-1/2 to 4 foot range. Very little dead fall was present here. Trees averaged approximately 60 per acre.

Five Mile House, Site B (dense) (3700 feet) - This site was in the same general area as Site A above, but it was burned-over area 20 years ago and has a covering of naturally seeded ponderosa pine and Douglas Fir seedlings 4 to 15 feet in height and broad-leaf maple 3 to 5 feet in height. Trees and bushes grow very close together.

Wolf Mountain Site (1600 feet) - This site was in dense chaparral with white-leaf manzanita (Arctostaphylos viscada) and A. manzanita the dominant plants. Poison oak (Rhus diversiloba) and Pinus ponderosa seedlings were also present as well as a few plants of buck brush (Ceanothus cuneatus). Bushes ranged from 2 to 7 feet in height with an average near 5 feet. Ponderosa pine seedlings were so widely spaced that they were not significant to visibility. The brush was very close together, forming an almost continuous ground cover.

APPENDIX B

Summary of Visibility Measurements

Mid-Latitude Mixed Forest
Sudbury, Mass., Sept. - Oct. 1963

18 September 1963

	Human				Clipboard			
	(OG 107)		(White)		(OG 107)		(White)	
Station	Erect	Prone	Erect	Prone	Erect	Prone	Erect	Prone
A	89.19	81.1	156.8	128.39	57.45	70.3	110.8	105.4
C	71.63	84.47	112.17	116.23	48.0	67.6	87.17	86.49
D	53.39	39.19	67.6	50.0	38.5	30.4	46.6	32.4
E	139.9	129.7	189.75	170.83	130.4	117.58	139.2	126.4
Av.	88.5	83.63	131.48	116.36	69.7	71.5	95.95	87.71
Direction								
N	97.6	75.0	133.8	87.16	66.9	63.5	94.6	80.0
E	106.19	95.96	140.56	128.39	81.7	79.74	104.7	86.5
S	70.95	77.7	116.9	103.39	69.6	79.7	95.3	90.5
W	80.41	85.8	145.96	151.37	56.1	62.8	93.2	100.1

8 October 1963

	Human (OG 107)		Clipboard (White)		Disk (White)		
Station	Erect	Prone	Erect	Prone	Erect	Prone	
A	98.8	92.5	113.9	109.1	131.2	103.1	
B	50.6	59.4	101.8*	81.7	64.8	81.0	*due to several trials in and out with clipboard.
C	70.2	77.2	80.2	91.3	86.4	91.8	
D	122.2	61.4	138.4	56.0	145.8	56.0	
E	135.7	110.0	299.7	253.8	224.0	189.0	
Av.	95.5	80.1	146.8	118.3	130.4	104.2	
Direction							
N	77.8	85.6	97.2	101.5	98.8	98.2	
E	113.4	94.5	110.0	80.3	158.4	112.5	
S	85.6	69.3	81.7	75.6	165.5	104.5	
W	106.1	84.9	117.4	84.2	130.4	91.0	

All distances in feet.

Summary of Visibility Measurements

Northern Coniferous Forest
Kluane Lake, Yukon, August 1963

Moving human target wearing

Feet	USMC utility dress (green)		Red sweater		TOTALS	
65-69	1	1			1	1
70-74	0				0	
75-79	1	> 1			1	> 1
80-84	0				0	
85-89	1	> 1			1	> 1
90-94	1		4		5	
95-99	3	> 4	2	> 6	5	> 10
100-104	0		3		3	
105-109	3	> 3	3	> 6	6	> 9
110-114	2		3		5	
115-119	2	> 4	3	> 6	5	> 10
120-124	3		6		9	
125-129	3	> 6	3	> 9	6	> 15
130-134	4		1		5	
135-139	2	> 6	5	> 6	7	> 12
140-144	7		7		14	
145-149	2	> 9	0	> 7	2	> 16
150-154	3		6		9	
155-159	6	> 9	5	> 11	11	> 20
160-164	0		1		1	
165-169	3	> 3	2	> 3	5	> 6
170-174	1		0		1	
175-179	4	> 5	1	> 1	5	> 6
180-184	4		1		5	
185-189	2	> 6	3	> 4	5	> 10
190-194	0		0		0	
195-199	2	> 2	1	> 1	3	> 3
TOTALS	60	60	60	60	120	120